Introduction

Objectives

We, the members of the Hampton University Elementary Particle Physics group, propose to investigate the physics of multi-TeV collisions, to work with undergraduate and graduate students (most of whom will be African Americans), and to participate in outreach efforts, including the QuarkNet (QN) project. Our program is built around participation in the CERN ATLAS collaboration. Ours is a long-term project—the Large Hadron Collider (LHC) will likely operate in the year 2005 or later—so that the primary objectives for this proposal are those to be met in the early part of this effort, namely:

- To participate in the construction of the barrel region of the Transition Radiation Tracker (TRT), part of the Inner Detector of ATLAS
- To begin a physics program through simulation and studies of the physics performance of the ATLAS detector
- To strengthen the education of African Americans by involving undergraduates and graduate students in the program
- To participate in the QuarkNet program, which targets high school teachers and students, as a home for a QN staff member and as a QN center.

Background of Hampton EPP group

Hampton is an historically-black university (HBCU), with an undergraduate enrollment that is 80% African American and 64% female. It is one of the few HBCU's with graduate programs in physics, and is a leader in research on the fundamental structure of matter among HBCU's. Besides the newly established effort in particle physics at TeV energies, a group of faculty members, research associates, and students have been conducting experimental and theoretical research at Jefferson Lab.

The Department of Physics offered the first Doctor of Philosophy degree at Hampton University (beginning in 1992); it also has a Master's degree program. The Department has 14 tenure or tenure-track faculty members, with specialties in nuclear physics, optical and laser physics, atmospheric sciences, and now, elementary particle physics. There are a total of 46 graduate students pursuing advanced degrees, and 22 undergraduates. More than half of the graduate students, and all the undergraduates, are African American or Black. Additional information about the University can be found at www.hamptonu.edu.

In 1997, under the leadership of Professor Baker, Hampton joined the international ATLAS Collaboration [1], which will design, construct, operate, and study the data from, the ATLAS Detector [2], a large general-purpose detector to be installed in one of the interaction regions at the Large Hadron Collider (LHC) at CERN. The Hampton group is a member of the U.S. ATLAS collaboration[3], and the TRT group.[4] Dr. K.W. McFarlane joined the group in 1998. Dr. K. Assamagan became a member in 1998 also.

O.K. Baker has been spokesman for experiments at Jefferson Lab (on kaon electroproduction). He was responsible for the large drift chambers, which define particle trajectories in the Hall C High-Momentum Spectrometer, which have operated successfully since the beginning of the experimental program. He is a tenured Professor in the Physics Department and holds a joint appointment at Jefferson Lab.

K.W. McFarlane was co-spokesman for the experiment that provides the current best value of the important pion beta decay rate. For the kaon decay experiment (BNL E791) which gave the best limits on a variety of rare decays as well as the best measurement of the $K^0_L \rightarrow \mu\mu$ branching fraction, he was responsible for the gas Cherenkov counters, the muon trigger hodoscopes and the Level 1 logic. He also worked on tests of gas Cherenkov counters proposed as trigger devices for SDC. At the SSCL, he worked on the software systems for the GEM detector. He also built the counter hodoscopes and trigger logic for the (5m by 2m) cosmic-ray test stand that was used to validate designs for the muon chambers for GEM. He is a Research Professor at Hampton University.

Dr. K. Assamagan is currently a post-doctoral associate who has worked at Jefferson Lab; since joining the group he has been at CERN, working mostly on the Physics Technical Design Report.

We are hosting Mr. Ken Cecire, an administrator of the QuarkNet program. Mr. Cecire is a long-time local high-school physics teacher.   QuarkNet is a joint educational effort of Fermilab, U.S. ATLAS, and U.S. CMS.[5]

We have established a detector construction facility for the TRT at Hampton University and have already involved several African American students in the work. A 1.5-m prototype Transition Radiation Tracker module is under construction, and a detector test facility is being prepared.

Expected significance of research

The ATLAS Detector is one of only two detectors at the LHC to address the broad questions of fundamental physics for which the LHC program is primarily designed.

The crowning achievement of particle physics is the Standard Model (SM) with its unification of the electromagnetic and weak forces. However, electroweak unification naturally leads to *W* and *Z* mesons with a mass exactly zero, like that of the photon. Since the *W* and *Z* have masses close to 100 GeV, there must be a mechanism that breaks this symmetry (e.g., the presence of a Higgs boson). We do not know what that mechanism is, but we do know that the mechanism must be evident in particle systems at the 1 TeV level. The exploration of the 1 TeV mass scale therefore has the highest priority in particle physics, with a high-luminosity multi-TeV proton-proton collider and associated detectors being seen as the most effective way to reach the necessary energy and luminosity. In addition, collisions at these energies, much higher than at any existing laboratory, will allow exploration of strong interactions in a new energy range.

For these reasons, CERN is constructing the LHC, a proton-proton collider to be completed in the year 2005. The energy available in the center-of-mass system will be 14 TeV and the design luminosity 1×10^{34} cm^{-2} s^{-1}. This high luminosity constitutes a major challenge to the detector, which must cope with an average of 18 events in a given beam crossing, and with potential radiation damage to the detector elements. ATLAS is designed to meet this challenge, while maintaining sensitivity to many possible interaction topologies.

According to many current models, there must be some new physics in the energy range covered by the LHC and ATLAS (and CMS). This project will therefore lead to discoveries about the fundamental structure of matter of great significance, whether it is discovery of one or more Higgs bosons, Supersymmetric particles, or something not anticipated.

Relation to longer-term goals

As Principal Investigators, our long-term goals are:

- To advance understanding of particle physics
- To increase the number of under-represented minorities (particularly African Americans) entering careers in science and technology.

The construction, installation and operation of the ATLAS TRT and a continuing effort on physics studies through a program of simulations, followed by analysis of data from ATLAS will put us in an excellent position to meet the first goal.

Since our effort is now situated on campus at Hampton University, and we plan to establish programs at local high schools with large African American populations (as described in a later section), we believe we are well placed to meet the second.

Relation to present state of knowledge

Leading candidates for physics discoveries include the Higgs boson and supersymmetry (SUSY). No direct evidence for either of these exists today.[6]

For the Higgs, the best constraints come from LEP.[7,8] For the Standard Model (SM) Higgs boson, the lower bound on the mass is 102.6 GeV. On the other hand, global fits to the SM predict a mass of 77^{+69}_{-39} GeV/c^2, implying that the most likely mass is just above the current lower bound.[8]

For the Higgs bosons of the Minimal Supersymmetric SM, lower bounds of 84 GeV for the neutral Higgs bosons, and 77 Gev for the charged Higgs, are obtained.[7] For SUSY, lower bounds of about 90 GeV for sleptons and charginos, and 200 GeV for squarks and gluinos have been set by LEP-II and the Tevatron.[6]

The ATLAS detector is designed with many criteria in mind: sensitivity to the largest possible Higgs mass range; the ability to search for heavy *W*- and *Z*-like objects, supersymmetric particles, and compositeness of the fundamental fermions; and the ability to investigate CP violation in *B*-decays and make detailed studies of the top quark. At the five-standard-deviation level, a SM Higgs boson from 80 GeV to 1 TeV will be discovered, if it exists in that mass range. In addition, most of the Higgs parameter space of SUSY models will be covered, and direct observation should be possible for SUSY particles to 1 TeV/c^2 and above.[9]

The ability to cope well with a broad variety of already-conjectured physics processes is expected to maximize the ATLAS detector's potential for the discovery of new, unexpected physics. Emphasis is also put on the performance necessary for pursuing the physics accessible during the initial lower luminosity running (10^{33} cm^{-2} s^{-1}), using more complex signatures such as τ-lepton detection and heavy-flavor tags from secondary vertices.

Relation to work in progress elsewhere

With regard to the Higgs, a discovery is possible before LHC turn-on at both LEP-200 and the Tevatron. At LEP-200, a SM Higgs boson of 104.5 (107.0) GeV/c^2 can be discovered

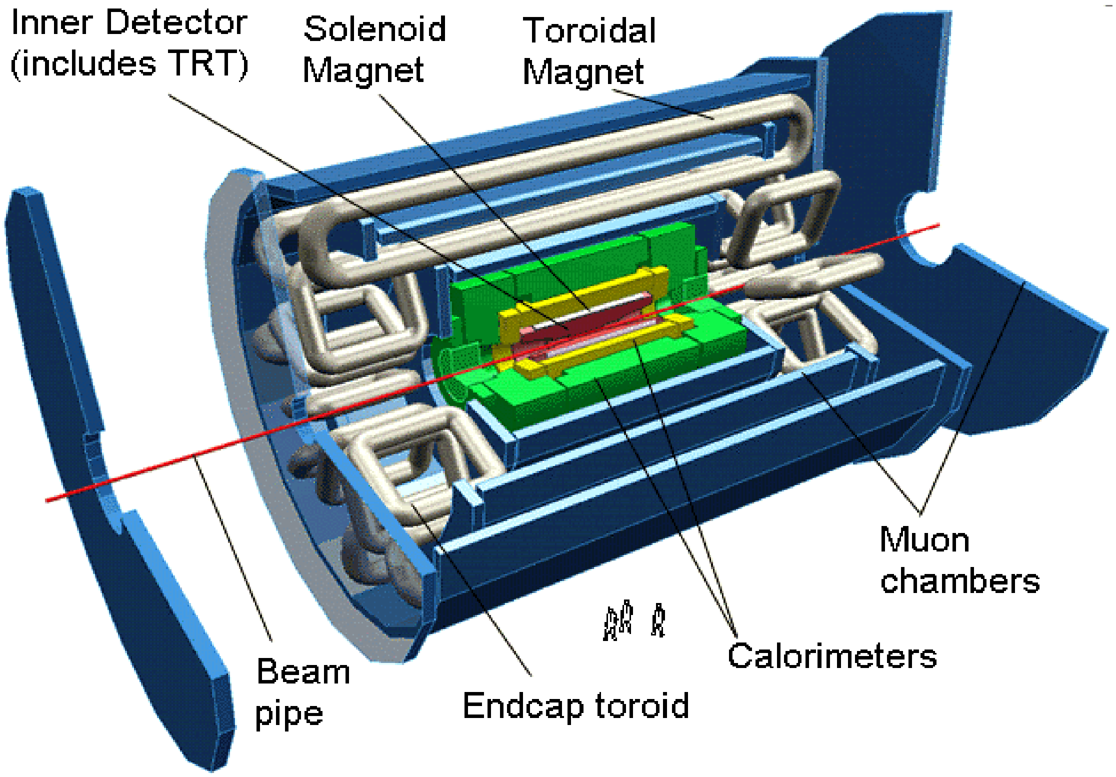


Figure 1 - Main features of ATLAS detector.

(excluded).[10] At the Tevatron, in Run II (2 fb^{-1}), the 95% CL limits will barely extend the LEP-II limits, but with 10 fb^{-1} in Run 3, the SM Higgs can be excluded up to 190 GeV/c^2 if it does not exist in that mass range. In Run 3, with 20 fb^{-1}, if a SM Higgs exists with mass less than 180 GeV/c^2, the combined sensitivity of CDF and DØ will yield an observation at the 3σ level up to 180 GeV/c^2 mass.[11]

For SUSY, even if a discovery is made at the Tevatron, only the LHC will be able to explore the specific structure of supersymmetry.

Relation to work in progress by the PI under other support

One of the PIs (Dr. Keith Baker) is also involved in the experimental program at Jefferson Lab, studying kaon electroproduction and hypernuclear physics in the multi-GeV range. The CEBAF machine explores the precision frontier using high beam intensities and luminosities.

Both PIs have other current awards that support the ATLAS effort; these awards are listed in a later section of this proposal.

Description of the ATLAS Detector

To put the proposed work in context, a brief description of the ATLAS detector, with some detail on the TRT, is given here.

The overall detector layout is shown in Figure 1. Magnetic fields and tracking detectors are used to determine particle momenta, with calorimeters measuring energies. The magnet configuration is an inner superconducting solenoid around the inner detector cavity, and large superconducting air-core toroids outside the calorimeters.

The inner detector is contained within a cylinder of length 6.80 m and radius 1.15 m, with a solenoidal magnetic field of 2 T. It is a tracking detector with silicon pixel and strip detectors close to the vertex followed by drift-tube (straw) detectors with transition radiation detection capability.

A combination of liquid argon (LAr) calorimeters and a novel scintillator-tile calorimeter is used to measure electromagnetic particles and hadrons out to a pseudorapidity of 4.9.

The calorimeters are surrounded by the muon spectrometer, which has high-precision tracking chambers and fast trigger chambers and uses the barrel and endcap toroidal magnets for momentum measurement. The muon spectrometer can operate alone at high luminosity.

The Inner detector (figure 2) has two sub-systems: the Semiconductor Tracker (SCT) and the Transition Radiation Tracker (TRT). The SCT plays a primary role in charged particle tracking in the ATLAS detector, using pixel and silicon strip detector devices. The TRT will be used to refine the trigger, will contribute to pattern recognition, and will help identify electrons and reject backgrounds to key processes, such as $H \rightarrow \gamma\gamma$. It must operate reliably over the ten-year lifetime of the experiment. A full description of the TRT and its performance can be found in the recently-submitted Technical Design Report [12].

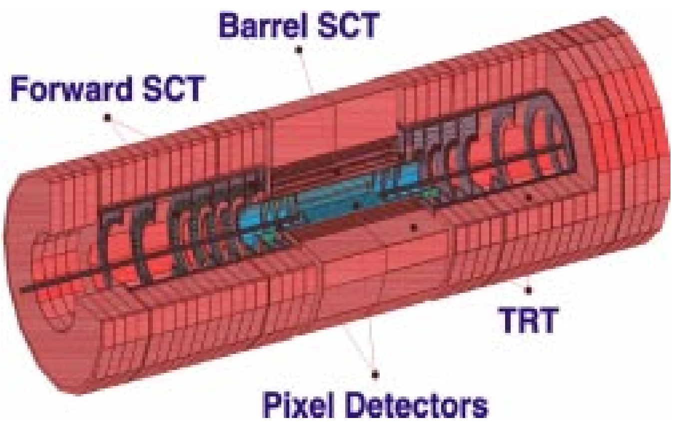


Figure 2 - Schematic of ALTAS Inner Detector

The barrel region of the TRT will be constructed by a collaboration of four U.S. universities: Duke University, Indiana University, Hampton University for chamber construction, and the University of Pennsylvania for electronics.[4] The schedule for construction is that it be completed in the year 2002. It is a significant responsibility in one of the major future experimental programs in particle physics.

Transition Radiation Tracker (TRT)

The TRT is a combined straw tracker and transition radiation detector that provides tracking information and contributes to the electron identification over the whole inner detector rapidity coverage. The TRT occupies the outer 60 cm of the inner detector cavity. Its tracking system consists of more than 370,000 straws. The TRT has three different sections - two endcap detectors with radial straws and one barrel detector with straws oriented parallel to the magnetic field direction. The barrel TRT measures (r,ϕ) while the endcap TRT measures ϕ and z (in a cylindrical coordinate system z,r,ϕ, with z parallel to the beam).

Robust pattern recognition capability in the barrel region is provided by 73 evenly-spaced layers, which produce >36 measurement points per track with $p_T > 1$ GeV/c. TRT measurements are combined with those of the SCT detectors to perform the momentum determination. The TRT is used in the Level 2 trigger and its non-stereo geometry was designed to be compatible with that use. Figure 3 shows the arrangement of the straws in three modular layers held in a low-mass space frame. Figure 4 is a cutaway view of a module.

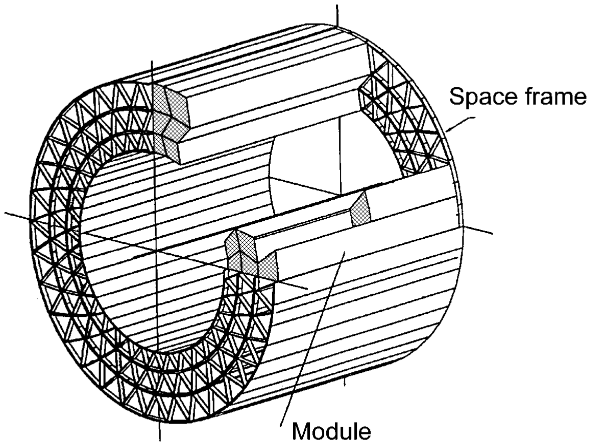


Figure 3 - ATLAS barrel TRT, showing arrangement of modules and supporting

The barrel TRT covers ± 75 cm in *z* and consists of three sections radially, each with 32 modules (fig. 3). The inner radius is 560 mm and the outer 1070 mm. Each wire is 150 cm long and is divided in two at the center giving two readout channels per straw, and halving the occupancy. The modules in the inner section have 329 straws in 19 layers, the middle section has 520 straws in 24 layers, and the outer section 793 straws in 24 layers. The radial spacing between straws is 6.8 mm. The total number of straws in the barrel TRT is 52344 straws, with 105088 electronics readout channels.

Radiators interleaved with the straws generate transition radiation for particles of very large Lorentz factor (γ), giving electron identification independent of energy-momentum matching. The soft X-rays of the transition radiation convert in the xenon gas in the straws. Besides having a low threshold appropriate for minimum-ionizing particles, the electronics has a high threshold (of about 6 keV equivalent) to detect these conversions. This information is particularly useful at lower transverse momenta (<5 GeV/c).

A module (figure 4) consists of a carbon-fiber composite shell for mechanical support, HV and wire-tensioning endplates, and the straws and radiator material. Low-mass dividers across the interior of each shell, with an appropriate pattern of holes, will align the straws on a 25-cm spacing. The transition radiators are made from specially-woven polypropylene fiber.

The 4-mm diameter straws are made by overlapping two 25-μm thick Kapton strips, each covered with 200 nm of aluminum followed by 4 μm of a carbon-filled polyimide. The straws are reinforced by gluing four carbon fibers along the straw wall to give stable mechanical properties. A 30-μm gold-plated tungsten sense wire is stretched along the straw axis. The chamber gas is 70% Xe + 20% CF_4 + 10% CO_2, with the xenon chosen for transition radiation detection. The straws operate at a gas gain of $\sim 4.0 \times 10^4$. The maximum drift time is about 38 ns for this gas mixture in a 2 T magnetic field. The expected intrinsic spatial resolution is 150 μm.

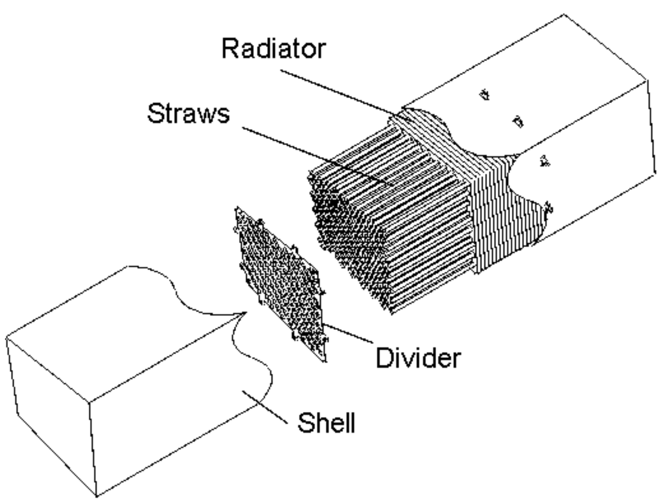


Figure 4 - Cutaway view of module, showing carbon-fiber shell, straw support 'divider' straws and radiator material.

The sense wire is supported and precisely located in the center of the straw and at the ends (figure 5) by wire guides with helical grooves that center the wire while allowing passage of active gas.

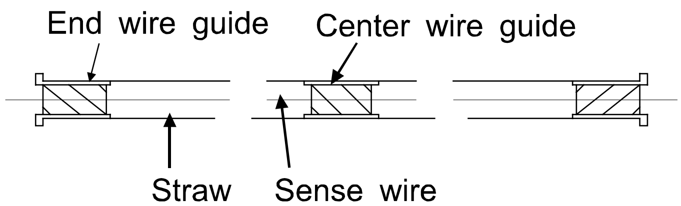


Figure 5 - Schematic of straw tube with wire guides and sense wire.

The detector design balances conflicting requirements: a minimum number of radiation lengths dictating a low-*Z* plastic-and-glue construction against requirements for mechanical rigidity, precision and stability to maintain gain uniformity, and radiation hardness to survive the integrated radiation dose from 10 years of LHC operation.

In the past three years several TRT prototypes have been built at CERN and in the U.S. They have been used to measure performance in a test beam and to check the engineering designs. The pion rejection factor was about 100 for an electron efficiency of 90% (at about 30 GeV), degrading to a factor of 20 at the expected maximum occupancy. Tests included measurements in a magnetic field of 1.56 T. Gain variation of full-length modules is acceptably small.

The highest local particle density will be reached at the inner radius of the barrel TRT, where the hit rate/channel will reach about 20 MHz at the LHC design luminosity. The impact of this environment on the tracking performance was studied in two separate experiments. One was with straws in a beam, simultaneously irradiated by an X-ray source, and the other was using cosmic rays while straws were radiated by intense ^{90}Sr sources. Neither unexpected inefficiency nor deterioration of the spatial resolution is observed.

Most components and materials have been exposed to fast neutrons, slow neutrons, and ionizing particles at doses comparable with that expected in the detector lifetime, using facilities at Duke and Indiana. No changes in straw properties were observed. The anode wires have received integrated charges (up to 10 C/cm) corresponding to fourteen years of LHC running, with no aging or cathode etching observed. Radiation hardness testing and out-gassing studies for the various components and glues have been completed.

Following various reviews, including a Production Readiness Review in December 1998, the barrel TRT has been approved for production. Still, there are still many issues to be resolved, and the move from prototype to production requires many changes and refinements in the manufacturing processes.

Plan of work

In the period of this proposal, we will work on the following tasks:

- Preparation of components for assembly into TRT modules
- Testing and wire-position surveys of completed modules
- Beam tests related to TRT performance
- Physics studies

In addition, Hampton University will host the annual TRT workshop in June 2000, for all TRT institutions. Previous workshops have been at CERN, PNPI (Gatchina), Indiana, and Krakow.

The components will be prepared in the new production facility at Hampton University, consisting of a clean room and support space. An X-ray module survey stand is presently under construction in an adjacent area. At the same time, physics studies will be continued.

In the sections below, we briefly describe the status of barrel TRT construction from the point of view of production readiness and schedule, and then go on to describe the activities planned at Hampton.

Current Status of barrel TRT construction

Design of components has been completed, with some exceptions. Production is underway, of shells, straws, radiators, wire guide parts, tension plates and HV plates. The pre-production phase lasted longer than expected and is still incomplete – production is six months behind schedule. Although the schedule is now very tight (see table 1), the schedule for installation can be met, given adequate funding.

Table 1 – Current TRT Barrel Schedule

Task	1998	1999	2000	2001	2002	2003	2004
Prototype R&D	-------|						
Pre-production	|--------|						
Production		|---------------------|					
Installation					|-----------------|		

Component Preparation at Hampton

The first task is to go from the tooling used to produce prototype and pre-production parts to production-capable tooling, and the budget requested reflects that. During our preparation of approximately 2,000 straws for one prototype and two pre-production modules, we learned the limitations of the existing equipment for reliability and production rate. Using this experience, we have designed an upgrade program to reach production rates needed to get back on schedule while maintaining quality.

Specific component-preparation tasks are:

- Straw preparation (gluing in the center wire guide, leak checking, resistance and straightness testing, cutting to final dimensions)
- Wire guide assembly (center and end)
- Divider assembly
- Radiator pack assembly
- Capacitor barrel and capacitor assembly
- High-voltage plate inspection
- Production database implementation
- Packaging and shipping to protect parts from humidity and other damage.

Each of these tasks has a number of sub-tasks with a need for tooling and pre-production engineering, as well as data recording and documentation. Looking, for example, at straw production, the steps are as follows:

- Rough cut to length
- Glue center wire guide in place (the guide is previously assembled from two pieces)
- Leak check
- Check straightness of straw and resistance of conducting films
- Cut to final dimensions.

Each step above requires tooling to process of the order of 60,000 items, approved instructions, quality-control procedures, and database requirements.

We will not go into details of each of the above items, but simply note that our budget justification separately lists estimated costs for each category, to meet the required schedule.

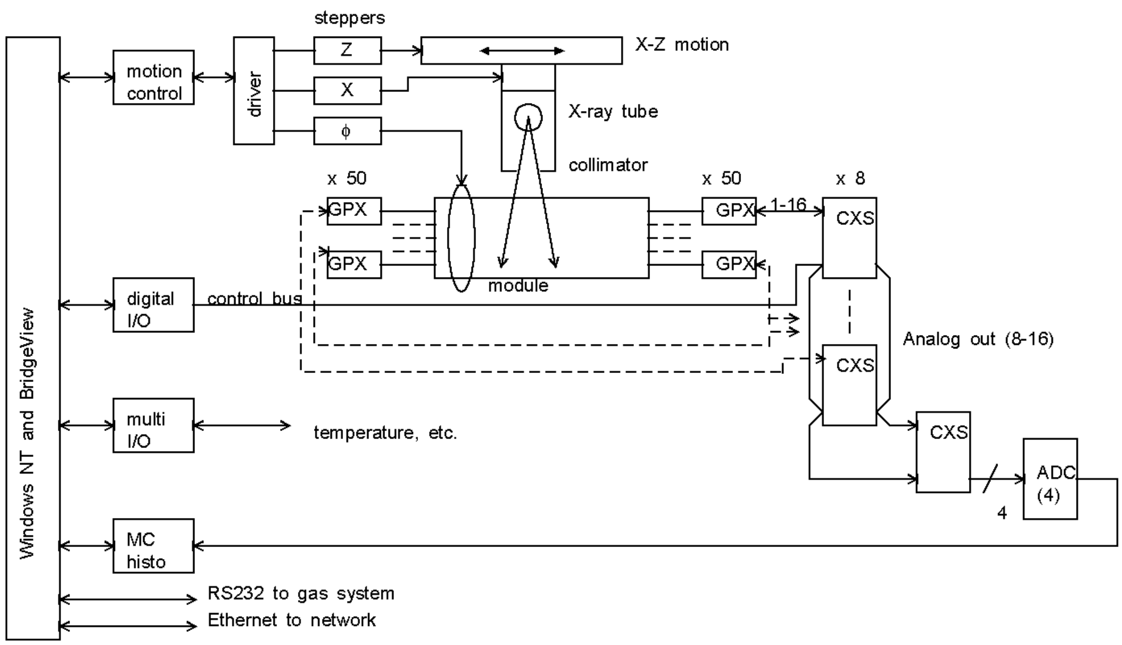
One aspect worth noting is that the ATLAS management requires full traceability on all items, meaning that all components must be traceable back to the manufacturer, and all aspects of production are to be recorded in a database.

Testing and survey of completed modules

We are in the process of constructing an X-ray survey system (XRSS) for gain and wire-position surveys on completed barrel TRT modules. The X-ray tube chosen will operate up to 80 kV and 60W; it has a spot size of 0.01-0.05 mm, and the beam will be collimated to approximately 0.05 mm wide and 10 mm long. The beam can be positioned within an area 1500 mm (Z) by 300 mm (X); the X-coordinate positioning will have a resolution of 0.01 mm or better. The schedule requires us to survey modules at the rate of one per week, with gain measurements every few millimeters. Thus we need up to 10^5 spectra per module. We will automate the process, and use high-rate data-acquisition so that this can be achieved.

The signal electronics are based on the CERN GasSiplex chip - a 16-channel preamplifier combined with an analog storage and multiplexing stage, operated in ‘transparent mode’ in which one channel is connected through to the output. The signals from the X-ray source are uncorrelated, so the usual type of HEP data-acquisition electronics is not useful. Although the electronics designed for the end-cap testing have similar requirements and use the same chip, this electronics is packaged to match the end-cap physical structure. As a result, we must re-package the front-end design, and create a different type of multiplexing system. A conceptual design is complete, and prototype boards are being designed. The analog output from any chip will be steered to one of four multi-channel analyzers, giving a maximum acquisition rate of 400 kHz. Design and fabrication of the electronics will be done during the coming months. The XRSS will be controlled by a Windows NT and BridgeView system; a schematic is given in figure 5.

Hampton X-ray survey system - proposed



Motion Control - Nat Inst PCI-Step-40X (open loop 4-channel stepper board)
Digital I/O - Nat Inst PCI-DIO-32HS (32-bit high-speed I/O board)
Multi-I/O - Nat Inst PCI-1200 (8 SE 12-bit ADC, 2 DAC, 24 DIO, 3 timers)
MCH - Multichannel histogram interface (FAST)
ADC - 4-channel (independent) ADC (FAST)

Driver - nuDrive 4SX-411 4-channel open-loop stepper driver
Steppers - NEMA 23 stepping motors
X-Z motion - crossed linear motions (Aerotech+Thomson)
X-ray tube - Trufocus TFX-3080 80 kV, 60W tungsten anode
GPX - TBB Gassiplex front-end (stamp) board
CXS - TBB Control and cross-point switch module
(TBB - to be designed and built)

K. McFarlane, May 1999

Figure 5 - Schematic of X-ray survey system.

Beam tests

Members of the Hampton group will participate in TRT beam tests, to gain experience and assist with the evaluation of modules and readout electronics.

Physics studies

We will continue with physics studies during the period of this proposal, building on the experience already within the group, as noted in the section on previous NSF support. Initial studies have focussed on the Higgs boson; other topics will also be investigated.

Staffing and Management

To carry out this program effectively, a full-time manager is needed, along with post-doctoral research associates and technical staff. We must augment the existing group: this proposal seeks funding for a full-time senior person, an additional post-doctoral research associate, and (for one year) engineering help and a technician, as well as funds for students. The demands of establishing the Hampton group, and of starting up the production phase, cannot be satisfied with less. In addition, we need the one-year increase in staff, to bring production back on schedule by the end of FY2000. Note that the schedule slippage is barrel-TRT-wide and is due to a longer-than-expected R&D phase.

The ATLAS project, appropriately for such a large, long-term project, has put in place a variety of management structures, including a formal system of reviews, formal documentation requirements, quality control procedures, and project scheduling. Necessary as this is, it does add to the management requirements. Dr. Baker will continue to look at physics opportunities, and the simulation requirements of physics studies, while Dr. K. McFarlane will manage the construction effort full-time.

The distribution of time committed to this proposal will be:

O.K. Baker - 25% ATLAS during the academic year, 100% during one summer month
K.W. McFarlane - 100% ATLAS during the calendar year
K.A. Assamagan - 100% ATLAS during the calendar year
Post-doctoral research associate (TBD) - 100% during the calendar year
Engineer (TBD) - 50% ATLAS for 2 years
Technician (TBD) - 100% ATLAS for one year.

Plans for documentation and sharing of data and other research products

Physics studies will be documented through ATLAS reports, available on the Web at the CERN-ATLAS web site and at the Hampton group web site. The results will also be shared through seminars and meetings.

The TRT detector itself will be documented in a variety of ways. The initial one will be through reports in the CERN engineering document system [13]. These reports will cover all aspects of TRT design, construction, and testing, from engineering drawings to quality control procedures. Articles on design, construction and performance (in beam tests and in ATLAS) will be prepared as ATLAS reports and submitted for publication. Currently, experience is shared among TRT institutions via regular meetings.

Information on straw technology and sample straws have been shared with a company interested in detectors for medical purposes.

Broader impacts

The impact on science will be significant, through the development of new detector technology, and through new observations in an unexplored energy range. There may be a possibility of spin-off of straw technology to medical imaging uses. Participation in this forefront project will have great educational impact at Hampton. It will enhance minority participation in high-energy physics and science generally, through research participation by undergraduates and graduate students. The QuarkNet program will also help recruit students to science, as well as enriching the teaching of science at the high-school level for many students.

Integration of research and education

Moving the construction activity from Jefferson Lab, where it began, to the Hampton campus was undertaken to integrate research and education. We plan to involve students at the high school, undergraduate and graduate levels in our work (we had two undergraduates and two high students working on this project in the last year – three African American males and one woman). Undergraduates will work on the production of components and on the testing of modules. Graduate students, beginning in 2001, will work on module testing, beam tests, and physics studies. Beginning at that time gives the possibility of a Ph.D. dissertation on ATLAS data, provided the LHC and ATLAS schedules hold. The availability of research topics in the exciting area of particle physics at Hampton, will, we hope, attract minority students to this field. Our involvement in the QuarkNet program, through teachers from local high schools, with their high proportions of African Americans, is intended to bring students into science and technology, as well as increase public understanding of science.

QuarkNet is one of the most ambitious efforts to link research in physics to education, through the creation of QuarkNet Centers.[5] During the lifetime of the project 60 universities and laboratories from 28 states will participate as QuarkNet centers. The model for the QN center uses two Lead Teachers working during the summer with physicist mentors on cutting-edge research at National Laboratories and at universities. The Lead Teachers recruit up to 10 local associate teachers, who also are introduced to high-energy physics research over several summers. These teachers then develop, use, and share, classroom activities related to HEP. QuarkNet funds stipends and travel for the first three years of the life cycle of a QN center. The QN center is expected to maintain its program, including summer research experience, with research and related sources of funding.

We expect to become a QuarkNet center during the period of this proposal. We currently host a member of the QN administrative team (Mr. Ken Cecire).

Participation of under-represented groups

It is well known that the proportion of African Americans entering careers in science is very small, and that participation in research at an early stage can greatly influence career choices. We expect our program of involving Hampton undergraduates in research to encourage students to enter careers in science and technology. Other important factors are visibility of graduate programs in the African American community and the possibility of mentoring relationships. This proposed research program will provide both research opportunities and mentors, and Hampton has M.S. and Ph.D. programs. In addition, we hope to add a QuarkNet program to reach high-school teachers and students in local school systems, which have a large proportion of African American students. We therefore expect our programs to be significant in raising the level of participation of African American students in science and technology.

Enhancement of infrastructure for research/education (facilities, instrumentation, networks, partnerships)

Hampton University has provided a 120-m^2 (1,300-ft^2) clean room and 90-m^2 office area to support this project. This is a new facility for detector construction. In addition, the X-ray scanner and associated instrumentation will be a significant new facility for detector studies. The project is itself a partnership between Hampton and the barrel TRT institutions, and the ATLAS collaboration as a whole.

Dissemination to enhance science and technology understanding

The QuarkNet program will reach the largest audience. If we do not become a QN center (there are many applications) during the period of this proposal, we intend to develop other means of making the local community aware of the ATLAS project, its significance and scale, and of Hampton's participation, including our website and that of U.S. ATLAS.[14]

Potential benefits to society at large.

The primary goal of this program is intellectual – finding answers to fundamental questions about the nature of matter. Some spin-offs are possible. For example, the TRT drift-tube technology is uniquely robust, and may have medical imaging applications (we are at present providing some technical help to a medical imaging firm).

Substantial collaboration with individuals not in budget

The barrel region TRT is primarily a U.S. ATLAS responsibility, in which the Hampton group will share (see the letter of support, page I-1, from Prof. Harold Ogren of Indiana University, who is the U.S. TRT subsystem manager [4]). Overall, we are part of the ATLAS collaboration, and both contribute to that effort and benefit from it (see the letter of support, page I-2, from Dr. Daniel Froidevaux of CERN).

Results from Prior NSF support

We combine here the information on prior awards to either Principal Investigator.

(a, b) Award number, amount and period of support, and title

Prior support is listed in Table 2, which lists the NSF award number, the PI, the amount to date, the period (up to and including the present period) and the title. Note that two grants were transferred with the PI to Hampton University, along with the unexpended balance. Some awards are sub-awards, where the main award is to another institution. In this case, the amount is the amount of the sub-award to Hampton and both the local PI and the main PI(s) are noted.

Table 2 - (a, b) Award number, amount and period of support

Award Number	PI	Amount	Period	Title of Project
9722827	B	$300k	9/97-8/99	High Energy Physics at the LHC
9724370	B	$265k	1/98-12/00	ATLAS Transition Radiation Tracker Instrumentation
9724148	M	($150k)	9/97-8/98	Transferred to Hampton U. as 9996185.
9996185	M	$142k	9/97-12/99	Research in Particle Physics with ATLAS at LHC
9724493	M	($265k)	9/97-10/98	Transferred to Hampton U. as 9996190.
9996190	M	$265k	9/97-12/99	ATLAS Transition Radiation Tracker Instrumentation
9819486	B,1	$30k	1/99-8/99	QuarkNet
9722537	B,2	$538k	1/99-12/9	Construction of ATLAS detector at LHC
9722468	B,2	$133k	8/97-8/99	ATLAS experiment at the LHC

B – O.K. Baker, Hampton University
M – K. McFarlane, Hampton University
1 – M.G. Bardeen (FNAL), O.K. Baker, R. Michael Barnett (UW), R.C. Ruchti (Notre Dame).
2 – William J. Willis (Columbia University).

(c) Summary of the results of the previous work, including human resources impact

The Hampton group has grown from a single investigator to three physicists, a production engineer and two technicians, since its inception in 1997.

TRT construction

We have established a production facility at Hampton University, in a new clean room (designed to be Class 10,000). This move was accomplished in October 1999; most of the previous work was carried out using Jefferson Lab facilities.

We are building a staff of full-time technicians (a senior research technician and a lead production technician were recently hired), with a focus on previous experience with high-tech assembly and quality assurance experience. We are relying less on contract personnel, though we have a valuable contractor as production supervisor.

We have processed a total of approximately 2,000 straws for the Hampton prototype module, the Indiana pre-production module 3.0 and the Duke pre-production module 2.0. As a result of this experience, we have re-designed and rebuilt most of the tooling used for straw processing to improve throughput.

For example, the straws must meet a stringent standard of gas-tightness, of less than one part in 10^{-7} s^{-1}, to control the cost of xenon, and to prevent build-up of xenon between the straws. A recommendation of the Production Readiness Review was modification of the straw leak-checker, to test multiple straws and automate the procedure. The leak-checker works by detecting pressure changes of the order of 3 μbar (0.001" of water). We have completed the first stage in this process: a two-straw tester with electrical control. Full automation will follow.

Other items include a wire guide assembly jig, a new jig for gluing wire guides in straws, a new machine for cutting straws to final dimensions, new tooling for divider assembly, and new processes to accelerated production.

TRT module survey

The Hampton prototype module mentioned above is a full-length module we are building to get experience with all phases of detector construction, and the end use of the parts we will process. It will also be used to exercise the X-ray survey system. The mechanical part of the module has been completed, and it is now being strung with sense wires in the Hampton clean room.

We are in the process of building the X-ray test system. Mechanical motion parts and motion control equipment have been delivered and work has started on the front-end electronics.

Physics studies

Dr. Assamagan has completed two studies of the physics performance of ATLAS in detecting charged Higgs production. One of these studies was included in the ATLAS Physics TDR.[9]

The first was a study of the possibility of detecting the charged Higgs through its hadronic decay modes, in the context of the Minimal Supersymmetric Standard Model with the assumption that the mass scale of supersymmetric partners of ordinary matter is above the charged Higgs mass.[15] For the charged Higgs mass below the top quark mass, the decay $H^{\pm} \rightarrow c\bar{s}$ can be used to determine the mass of the charged Higgs assuming it is discovered through other channels, for instance $H^{\pm} \rightarrow \tau\nu$, by observing the excess of τ production over the Standard Model prediction. Above the top quark mass, the charged Higgs can detected through $H^{\pm} \rightarrow tb$ up to 400 GeV/c^2 for low or high tan β (< 2, or > 20).

The second was a study of the possibility of detecting the charged Higgs through the process $H^{\pm} \rightarrow Wh^0$ with the ATLAS detector. [16] Good reconstructions of the charged Higgs and the neutral Higgs mass peaks are achieved below and above the top-quark mass and the $t\bar{t}$ background is suppressed quite significantly. However, because the expected low signal rates in either region, discovery potential seems limited to a rather narrow area of MSSM parameter space. The results can be normalized to other models, for instance NMSSM where it is believed there exists quite a range of discovery potential on either side of the top-quark mass.

Research Training, Outreach, and Education

Over the period of prior NSF grants, we have involved high school students and teachers, undergraduates and a graduate student. Most of the students have been African American (AA).

Ms. Alicia Johnson (AA) is now a graduate student in Hampton's Ph.D. program. She worked on the prototype module as a technician, and the availability of this work was instrumental in bringing her back into graduate study. She is now working on a Jefferson Lab experiment for her thesis.

Two Norfolk State students, Brandon Lucas (AA) and Kaleem Morris (AA) worked with us this summer (they are physics majors). A high school teacher (Ed Fisch) and student (Celia Reynolds) worked with us in 1998, and two high school students – Adrian Townsend (AA) and Sarah Fullerton – in 1999. Kaleem Morris worked on the prototype also; he was part of the UniPhy summer program and made a presentation on his project at the Annual UniPhy Lecture Series.

Resources for science and technology

The new clean room is a new resource for science and technology locally. The X-ray survey system and the computer and communications set up for the group at Hampton are significant additions to Hampton's resources. Of course, the TRT itself will be a resource.

(d) Publications from the NSF awards

There are no journal publications at this stage. The Hampton group contributed to the ATLAS Inner Detector TDR,[12] and the ATLAS Detector and Physics Performance TDR.[9]

(e) Brief descriptions of available data not described elsewhere.

We are adding relevant TRT construction information to the CERN engineering database (EDMS) as we proceed.[13]

(f) Relation of completed to proposed work

The completed construction work directly feeds into the proposed construction work. As for the physics studies, although we have focussed on the charged Higgs, we intend to explore other areas, especially those relevant to low-luminosity running where pattern recognition will be easiest and tracking performance best, at least initially.